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Fuzzy Logic Mamdani-Based Simulation of Solanum Lycopersicum Fruit Sorter to Produce High-Quality Fruit Products

Rahmat Fauzi Siregar[1)]*, Affandi[2)], Arya Rudi Nasution[3)], Hasanul Arifin[4)] & Muhammad Alwi Ripay Harahap[5)]

1,2,3,4,5) Department Electrical Engineering, Faculty of Engineering, Univesitas Muhammadiyah Sumatera Utara, Indonesia

*Coresponding Email: rahmatfauzi@umsu.ac.id

Abstract

This research presents a novel approach utilizing Fuzzy Logic Mamdani-based simulation implemented through MATLAB and SolidWorks for sorting Solanum Lycopersicum fruits to achieve premium fruit quality. By integrating advanced computational tools, the simulation emulates intricate sorting processes, enabling precise decision-making akin to human judgment. This innovative methodology offers a promising avenue for improving fruit sorting efficiency and product quality in agricultural industries. This simulation system uses loadcell sensors, color sensors and PIR sensors as input. These inputs are used to control three servos and one DC motor. The fuzification process is carried out on both the input and output sides. Based on the results of the fuzification process, eighty-one rules were obtained and a fuzzy inference process was carried out using the intersection method. After carrying out the fuzzy inference process, it is continued with the defuzzification process. The result of the defuzzification value on the quality output is 7324.99 in the high set and the result of the simulation of the quality output value is 7250 in the high set. Thus, the accuracy level of the simulation's results is 98.98%. The simulation results show that the system is able to sort low, medium and high quality Solanum lycopersicum fruit.

Keywords: Defuzzification; Fuzzification; Fuzzy Inference; Matlab; Simulation; Solanum Lycopersicum; SolidWorks.

INTRODUCTION

Tomatoes (*solanum lycopersicum*) are an agricultural commodity that has potential to be developed and cultivated in tropical areas because it has high nutrition and can be used by the community as a source of vitamins and minerals. The nutritional content and composition of tomatoes is very beneficial for health. Tomatoes are not only consumed as fresh fruit, but are also used as a flavoring ingredient and as an ingredient in the food and beverage industry (Quinet et al., 2019).

In Indonesia, tomato fruit production is very low, namely 6.3 tonnes/ha when compared with Taiwan, Saudi Arabia and India which are 21 tonnes/ha, 13.4 tonnes/ha and 9.5 tonnes/ha respectively. The low production of tomatoes in Indonesia may be due to unsuitable varieties being planted, poor cultural techniques or less efficient eradication of pests/diseases. Market demand for tomatoes continues to increase from year to year, namely in 2018 market demand for tomatoes in Indonesia was 976,772 tons, experiencing an increase of 4.46% in 2019 of 1,020,333 tons. The area of tomato cultivation in Indonesia has also increased by 1.15% from 54,158 Ha in 2018 to 54,780 Ha in 2019 (Halid, 2021).

The tomato processing industry is growing rapidly. One of the stages in the tomato fruit sorting process is selecting the fruit based on its quality (for example the level of ripeness of the fruit). There are many indicators that can be used to determine the level of ripeness of tomatoes during the sorting process, one of which is fruit color. The process of selecting agricultural and plantation fruit generally relies heavily on human perception of the color composition of the fruit (Johan & Rifna, 2022). The manual method is based on direct visual observation of the fruit to be classified. The weakness of manual classification of fruit is greatly influenced by the subjectivity of the sorting officer so that in certain conditions the classification process is not specific. Identification using this method has several weaknesses, including the relatively long time it takes and producing a variety of fruit due to human visual limitations, the level of fatigue and differences in perception about the quality of the fruit (Septimar et al., 2020).

The development of science and digital processing technology makes it possible to sort agricultural and plantation products automatically with the help of applications. According to the USDA, tomato ripeness levels are divided into 6 levels, namely green, breakers, turning, pink, light red, and red. Green ripeness levels are green tomatoes and can vary from light to dark. The Breakers ripeness level is green tomatoes with a slight pink color on 10% of the surface. The Turning ripeness level is that tomatoes are bright green and have a more pinkish color 10% on the surface. Pink maturity level is a tomato that has a reddish pink color on the surface between 30% and 60%. The Light Red maturity level is a tomato that has a reddish pink color between 60% and 90% on the surface. Red maturity level is a tomato that is more than 90% red in color to a dark red color on the surface (Denih et al., 2023).

Basically, this simulation system is designed using a load cell sensor, PIR sensor and TCS3200 color sensor. These sensor inputs are then processed using a microcontroller using the Mamdani fuzzy logic method which is used to sort tomatoes based on tomato weight, tomato water content and tomato color so as to obtain high quality tomatoes. A load cell sensor is a device used to measure the force or load on an object. Load cells work by converting the force applied to them into electrical signals that can be measured, the TCS3200 color sensor is an optical-based sensor used to detect and measure color on objects or surfaces and the PIR (Passive Infrared) sensor is a sensor used to detect changes in radiation infrared emitted by objects moving in an area (Sinclair, 2001).

Therefore, it is necessary to carry out a simulation of Solanum lycopersicum fruit selector based on mamdani fuzzy logic in order to obtain high quality fruit products.

RELATED RESEARCH

In their research (Jangam, 2023), they designed and implemented a conveyor belt system for sorting fruit quality using machine vision. This approach is intended to sort fruits based on their appearance, such as color, size and shape. The machine vision system was trained using a collection of photos of fruit of varying quality, allowing it to differentiate between high-quality and low-quality fruit. The conveyor belt system consists of motors, sensors, and cameras that capture images of the fruit as it moves along the belt. The machine vision system processes photos in real time, determining the quality of each fruit and directing them to the right container. The system's accuracy, speed, and efficiency are all measured. This technology is seen as having the potential to increase the efficiency and accuracy of fruit quality sorting in the fruit sector.

The process of grouping or sorting fruit that is currently carried out still uses manual methods carried out by humans. Basically, humans have characteristics that make the grouping or sorting process take a long time. Based on these conditions, a sorting machine is needed that has the ability to detect and group fruit based on color automatically and quickly. So it is hoped that making this machine can help productivity in the process of grouping or sorting fruit. The system created is a sorting machine that will classify the color of each fruit using a TCS3200 sensor as a color detector and all processes will be controlled using an Arduino with an ATmega328 microcontroller (Andi et al., 2021).

In their research (Henila & Chithra, 2020), they used the fuzzy cluster-based thresholding (FCBT) method to segment the desired region of the apple image which has been proposed for sorting apples in this research. As a first step, the obtained RGB color image of the apple is converted into a gray scale image. Then, five different fuzzy cluster bins with overlapping pixel ranges are taken and the gray pixel values are assigned to them. A cluster with the maximum number of pixels is selected to calculate the threshold value. The region of interest of the apple image is then segmented using the proposed FCBT values. Features extracted from segmented images are given as input to a fully connected deep neural network for classification. The performance of the FCBT method is compared with similar gray scale threshold methods such as the Otsu and Kapur methods. The visual segmentation accuracy and execution speed show that FCBT outperforms other methods in segmenting diseased areas. A fully connected deep neural network model with FCBT image extraction features as input values provides an accuracy rate of 98.33% in sorting apple images.

RESEARCH METHOD

In this research, a simulation of *Solanum lycopersicum* fruit sorting was created using SolidWork 2023 software and MATLAB 2018b software. This software is run on a laptop with specifications, Central Processing Unit Intel Core i7 7500U, Graphics Processing Unit Nvidia 940MX and runs on the Windows 11 Pro 64-bit operating system.

The automatic *Solanum lycopersicum* fruit sorting simulation system was created based on the Mamdani fuzzy logic method. Where, the simulation process for sorting *Solanum lycopersicum* fruit consists of input, process and output. Figure 1 shows the block diagram of the Solanum lycopersicum fruit sorting simulation process using fuzzy logic.

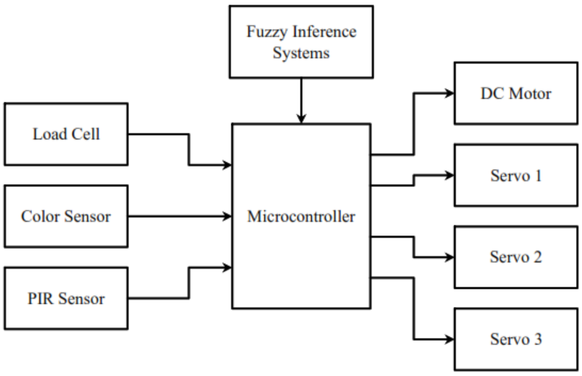


Fig 1. Block diagram of the *Solanum lycopersicum* fruit sorting simulation process using fuzzy logic

At the input stage, the *Solanum lycopersicum* fruit sorting system uses a load cell sensor which functions to measure the weight of the *Solanum lycopersicum* fruit, a color sensor which functions to detect the color of the *Solanum lycopersicum* fruit in 8-bit RGB (Red, Green, Blue) and a PIR sensor which functions to measure the amount of water content in *Solanum lycopersicum* fruit based on the reflection of IR (Infra Red) light received by the PIR sensor from the reflection of IR light emissions from *Solanum lycopersicum* fruit.

At the process stage, the three sensor input values are fuzzyified in order to map the crisp (numerical) sensor values into a fuzzy set and determine the degree of membership in the fuzzy set. After the fuzzyfication process is complete, inference is carried out which aims to change the fuzzy input into a fuzzy output by following the rules (if-then) that have been set in the fuzzy Knowledge Base. At the end of the process stage, a defuzzification process is carried out which aims to change the results of the inference stage into a crisp output using predetermined membership functions. This entire process aims to move the three servos and DC motors according to the specified output. Figure 2 shows the fuzzy inference system process.

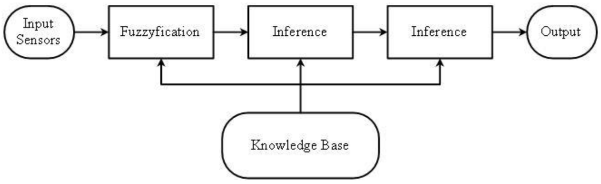


Fig 2. Fuzzy Inference System (FIS) process

At the output stage, each of the three servos will move according to the predetermined categories of bad, normal and good. Basically, the quality of *Solanum lycopersicum* fruit is divided into three categories including low, medium and high which are placed in each category container. *Solanum lycopersicum* fruit will be placed in each container by moving a conveyor that is actuated by a DC motor. The *Solanum lycopersicum* fruit will run on the conveyor and will stop at each category to be detected by sensor input and will move the servo to drop the *Solanum lycopersicum* fruit into the container in each category.

In the fuzzyfication process, the *Solanum lycopersicum* fruit sorting system was taken based on related research that had been carried out. At the load cell sensor input, weight measurements are expressed in grams, at the TCS3200 color sensor input, color detection uses 8-bit resolution for each red, green and blue (RGB) color channel. On a PIR sensor, detection is expressed on a 10-bit ADC scale. On the output side it consists of 3 MG996 servos and one DC motor. Each of these servos works independently based on a specified category, servo 1 for low quality, servo 2 for medium quality and servo 3 for high quality. Table 1 shows the fuzzyfication of each input and output.

Table 1. Fuzzyfication of each input and output

Input/ Output	Making Conclusion			Unit
	Fuzzyfication			
	Set		Crisp Value	
Load Cell	Light		0 - 100	grams
	Medium		80 - 145	
	Heavy		138 - 200	
Color Sensor TCS3200	Greenish	R	0 - 50	ADC 8-bit
		G	150 - 255	
		B	0 - 50	
	Yellowish	R	200 - 225	
		G	200 - 255	
		B	0 - 50	
	Reddish	R	200 - 255	
		G	0 - 50	
		B	0 - 50	
PIR Sensor	Less watery		0 - 340	ADC 10-bit
	Normal		341 - 680	
	Watery		681 - 1023	
Quality	Low		4000 - 5300	ADC 16-bit
	Medium		5000 - 6600	
	High		6500 - 8000	

At the output, the quality of the output unit is expressed in a 16-bit ADC scale. In the low quality category, servo 1 is on, servo 2 is off and servo 3 is off, where the ADC value range is 4000 - 5300. In the medium quality category, servo 1 is off, servo 2 is on and servo 3 is off, where the ADC value range is 5000 - 6600. In the high quality category, servo 1 is off, servo 2 is off and servo 3 is on, where the ADC value range is 6500 - 8000. Table 2 below shows the output conditioning.

Table 2. Output conditioning

Output quality	Actuator	Condition	16-bit ADC value
Low	Servo 1	On	4000 - 5300
	Servo 2	Off	
	Servo 3	Off	
Medium	Servo 1	Off	5000 - 6600
	Servo 2	On	
	Servo 3	Off	
High	Servo 1	Off	6500 - 8000
	Servo 2	Off	
	Servo 3	On	

After making conclusions, it is continued by determining each degree of membership on both the input and output sides using the mathematical equation of a triangular curve. Figure 3 below shows a triangular curve to determine the degree of membership of each input and output.

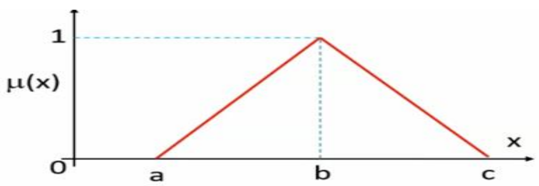


Fig 3. Triangular curve to determine the degree of membership of each input and output

All input and output variables are processed using Fuzzy Logic Designer software found in Matlab 2018b software. The mathematical equation for a triangular curve to determine each degree of input and output membership is expressed as follows:

$$\mu(x) = \begin{cases} 0; x \leq a \text{ or } x \geq c \\ \frac{x-a}{b-a}; a \leq x \leq b \\ \frac{c-x}{c-b}; b \leq x \leq c \end{cases} \quad (1)$$

Where, *μ(x)* is the value of the degree of membership of each set, *x* is the specified membership degree value, *a* is the minimum value of a set, *b* is the middle value of a set and *c* is the maximum value of a set.

The fuzzy inference or fuzzy rules used in this simulation system use the Intersection method or min operation with the AND operator. Based on making conclusions, there are as many as twenty-seven rules that can be made. All possible rules are input into Fuzzy Logic Designer in Matlab 2018b software (Evalina et al., 2023; Hooda & Raich, 2017).

After the fuzzy inference stage is made, it is continued with the mamdani defuzzification stage using the centeroid method, where this method takes into account area and moment. The following is the mathematical equation for mamdani defuzzification using the centeroid method:

$$z^* = \frac{\int z\mu_c(z)dz}{\int \mu_c(z)dz} \quad (2)$$

Where, z^* is defuzzyfication, $\int z\mu c(z)dz$ is the moment and $\int \mu c(z)dz$ is the area.

The next stage is to design a *Solanum lycopersicum* fruit sorting system based on mamdani fuzzy logic to obtain high quality fruit products using SolidWorks 2020 software. SolidWorks uses parametric design, which is why it's such an effective tool for designers and engineers. This means that the designer can see how changes will affect its neighboring components, or even the overall solution (Nasution & Widodo, 2022; Planchard, 2017). Figure 4 shows the design of the *Solanum lycopersicum* fruit sorting system.

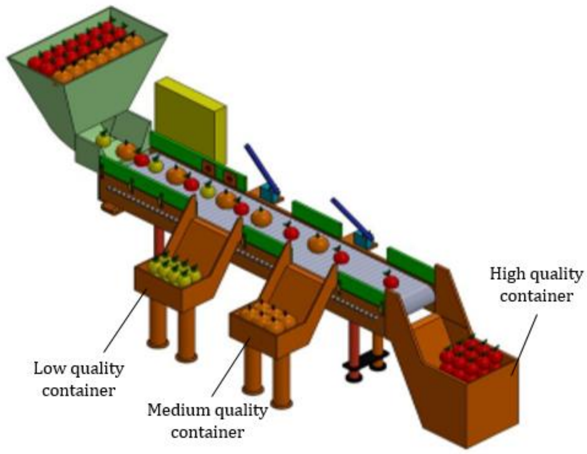
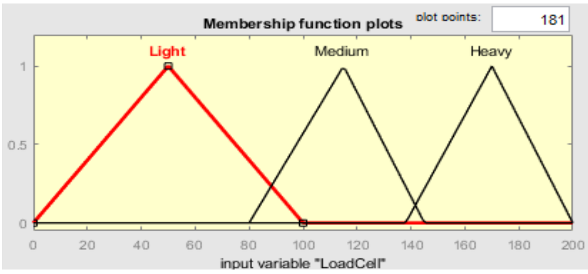


Fig 4. Design of the *Solanum lycopersicum* fruit sorting system

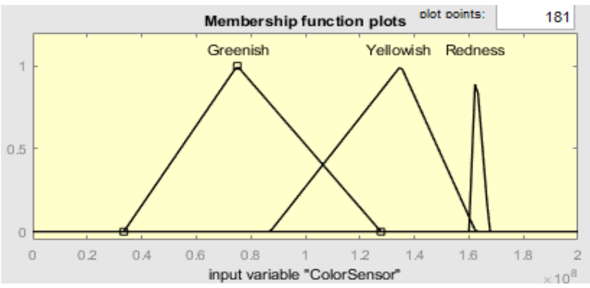
Based on the figure above, this system design has dimensions of Conveyor: 1200 mm x 300 mm x 500 mm, Hooper: 220 mm x 120 mm x 300 mm, Container: 200 mm x 250 mm x 320 mm and Panel Box: 200 mm x 200 mm.

RESULTS AND DISCUSSION

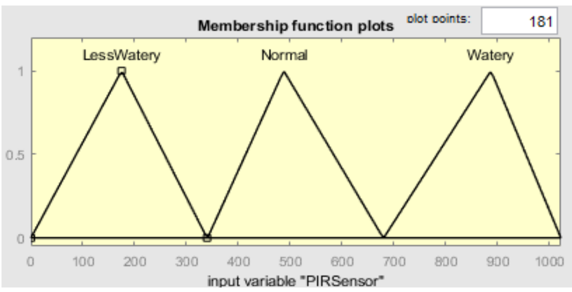
In this research, testing the results begins with determining the results of the fuziification process by determining the value of the degree of membership in each set, both on the input and output sides. The results of the membership degree values for the sensor input are shown in Figure 5 below.



(a)



(b)



(c)

Fig 5. (a). Membership degree value curve for the load cell sensor input set, (b). Membership degree value curve for the color sensor input set and (c). Membership degree value curve for the PIR sensor input set

From the figure above, the membership degree value of each set at the load cell sensor, color sensor and PIR sensor input is determined using the triangular curve equation. The value range for the load cell sensor is in the sets Light [0, 50, 100], Medium [80, 115, 145] and Heavy [138, 170, 200]. The range of values for color sensors is in the set Greenish [3340000, 7500000, 12700000], Yellowish [8700000, 13500000, 16750000] and Reddish [16000000, 16250000, 16750000] where the values are conversions from RGB values to Hexadecimal. The range of values for PIR sensors is in the set Less Watery [0, 175, 340], Normal [341, 488, 680] and Watery [681, 888, 1023].

After the membership degree values for all inputs are determined, then proceed with determining the membership degree value curve on the output side. The value range for quality output is in the sets Low [4000, 4700, 5300], Medium [5000, 5800, 6600] and High [6500, 7000, 8000]. Figure 6 shows the results of the membership degree values on the output side.

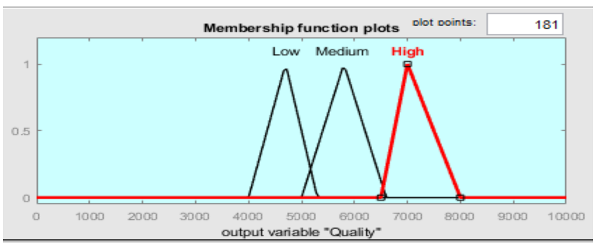


Fig 6. The result of the membership degree value on the output side

Based on the results of the fuzzification process, eighty-one rules were obtained. These rules are entered into the fuzzy inference process using the intersection method. The simulation results of the *Solanum lycopersicum* fruit sorting system based on Mamdani fuzzy logic are able to differentiate *Solanum lycopersicum* fruit with low, medium and high quality based on the method that has been applied. Figure 7 shows the simulation results of the *Solanum lycopersicum* fruit sorting system using Fuzzy Logic Designer in MATLAB.

Fig 7. Simulation results of the *Solanum lycopersicum* fruit sorting system using Fuzzy Logic Designer in MATLAB

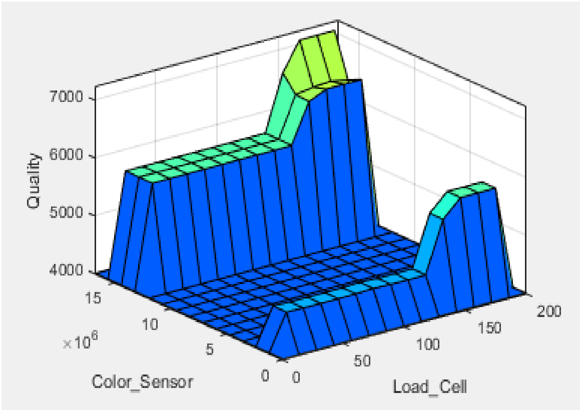
Based on the results of the simulation that has been carried out, when the load cell sensor input has a value of 110 in the medium set, the color sensor has a value of 15500000 in the yellowish set and the PIR sensor has a value of 812 in the watery set, then the quality output has a value of 7250 in the high set. The calculated results and the simulated results are not much different. Based on the calculation results, the results of the defuzzification of the quality output value are obtained from the following equation:

$$z^* = \frac{24.84486 \times 10^6}{0.00339179 \times 10^6} = 7324.99 \quad (3)$$

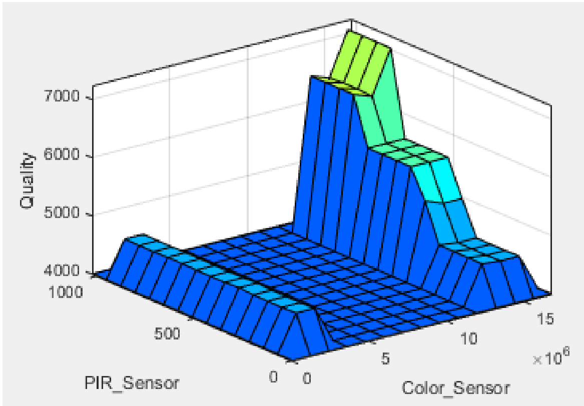
Where, z^* is the defuzzification value or quality output value, 24.84486×10^6 is the total moment value and 0.00339179×10^6 is the total area value. The total moment value and total area value are taken based on rules that fulfill the conditions between input and output. Therefore, the following equation can be used to express the value of the simulation accuracy level:

$$\%Accuracy = \frac{7250}{7324.99} \times 100\% = 98.98\% \quad (4)$$

The level of accuracy in this simulation is very high, so it can be concluded that this simulation can be implemented in real conditions. The relationship between the load cell sensor input, color sensor and PIR sensor greatly determines the output value. The load cell sensor input value range starts from 0 grams – 200 grams, the color sensor input value range starts from 0 – 16777215 in hexadecimal (R: 0-255, G: 0 – 255 and B: 0 – 255) in RGB and the value range PIR sensor input starts from 0 – 1023 on the ADC scale. Figure 8 shows a graph of the relationship between input and output.



(a)



(b)

Fig 8. (a). The relationship between the load cell input and color sensor to the output, (b). The relationship between the load cell input and color sensor to the output

CONCLUSION

The application of a fuzzy-based *Solanum lycopersicum* fruit sorting system using the Mamdani method to obtain high fruit quality can be implemented both in simulation and in real form. This system is able to precisely distinguish low, medium and high quality *Solanum lycopersicum* fruit. The use of the fuzzy logic method in control systems is very helpful in solving problems that cannot be solved by traditional control methods. By using the fuzzy logic method, control system problems that have multiple inputs to control multiple outputs can be solved well.

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